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VARIABLE STAR OBSERVING AT MONTREAL

By JOHN W. DUFFIE

IN June of 1942, Mr. DeLisle Garneau and I embarked on a programme of observation of a number of variable stars under the guidance of the American Association of Variable Star Observers. Some of the results of this two-year collaboration are given below, in the hope that these results may prove of sufficient interest to encourage other members of the Royal Astronomical Society of Canada to take up this absorbing and valuable branch of research.

Practically all the observations were made with the six-inch Aitchison refractor of the Montreal Centre, R.A.S.C., housed in the Ville Marie Observatory, 4052 Wilson Ave., Montreal, although a few of the brighter variables were studied with field glasses. All results were duly reported to the A.A.V.S.O., Harvard College Observatory.

In order to cover as much ground as possible, a list of all the variable star charts in our possession was affixed to the wall of the observatory, and at the conclusion of each night's work, the observer would mark his initials and the date only, after each star observed. In this way we could tell at a glance which stars required attention, and at the same time unnecessarily frequent observations of the ordinary long-period variables were avoided. The actual estimated magnitudes were recorded independently, thus eliminating any possible unconscious influencing of each other's observations.

During the two-year period under review a total of 1032 observations were made on 84 different variable stars, 674 by Mr. Garneau and 358 by myself. Of course, not all stars received the

same amount of attention. In fact, the fifteen stars most often observed accounted for 524 observations, more than half the total, while at the other end of the scale a few stars, being difficult to locate or being visible only in the coldest part of the winter, were only observed two or three times. Furthermore, while stars of the rapidly varying or irregular types require almost constant attention, even observations made on successive nights being of value, the regular long-period variables with well-established light curves need only be checked two or three times per month.

As might have been expected, the most frequently observed star was SS Cygni, the pet of variable star observers everywhere and probably the most thoroughly studied of all variables, which we observed 69 times. This star, described variously as a nova-like, explosive or cataclysmic variable, hovers quietly near the 12th magnitude for about two months, when it suddenly blazes forth almost overnight to nearly 8th magnitude. It never fails to provide a thrill when the observer, pointing his telescope at SS Cygni for "just another routine check," finds the star shining so brilliantly as to dwarf neighbouring stars which had outshone it a few nights previously. In the period covered by this report, five maxima of SS Cygni were observed, while on one occasion we were fortunate enough to catch the star at 9.2 magnitude, actually on the rise to a maximum. Observations at this stage are, of course, of particular value.

Second in number of observations was R Scuti, an easily located and exceptionally interesting irregular variable, of which 61 estimates were made. This star, situated in a beautiful field in the heart of the Milky Way, near the star cluster M 11, ranges from about 5th magnitude to 8th in an entirely irregular fashion. No complete explanation has ever been made to account for its fluctuations, and as its light curve does not follow any consistent pattern, no predictions can be made as to its future behaviour at any time.

Another interesting variable, to which perhaps we did not pay sufficient attention, is R Coronae Borealis, estimated on 17 occasions. This is another cataclysmic variable, but one which acts in just the opposite way to SS Cygni. R Coronae remains at nearly naked-eye brightness, about 6th magnitude, for an unpredictable length of time, sometimes for a year and again for as long as ten

years, then without warning it suddenly drops to 12th or even 15th magnitude, beyond the range of all but very large telescopes. In October of 1942 this star began one of its rare descents to minimum, but the constellation was nearing the sun at that time and this circumstance, together with a most unfortunately placed tree in the vicinity of our observatory, prevented the making of any observations.

The majority of the other stars studied are regular long-period variables, and were therefore not checked as often as the irregular types. S Ursae Majoris was observed 36 times, while RS and T in the same constellation were each estimated on 33 occasions. These three stars are all included on the same A.A.V.S.O. chart and are very easily found, being situated slightly to the north of the star Delta Ursae Majoris, at the junction of the handle with the bowl of the Big Dipper.

S Persei, situated near the spectacular double cluster Chi-h, was next with 31 observations, then some fifteen variables, including five in the constellation Cygnus, were estimated from twenty to thirty times.

As stated above, the stars of the winter skies were not followed as assiduously as those of the summer. However, S Geminorum received 16 estimations, X Aurigae received 10, while T Orionis, located in the Great Nebula of Orion, was also estimated 10 times. The scarcity of winter observations is at least partly explained by a note, in very shaky handwriting, appearing in the Observatory Journal under a date in January 1942, to the effect that observations were being made with the thermometer at $-20°$ Fahr.

An interesting fact revealed by our records is the strikingly different reaction of Mr. Garneau's eyes and mine to the light of deep red stars. On taking at random ten cases where a decidedly red star was observed by both of us during the same week, I find that in two instances our estimates were a full magnitude apart, twice we differed by .6 magnitude and on the other seven occasions by either .4 or .5 magnitude, Mr. Garneau's estimate in every case being the brighter. As we both use the "quick glance" method of observing in order to avoid the apparent brightening of a red star when gazed at for any length of time, the explanation must lie in some organic difference in our eyes, resulting in a different degree of sensitivity to red light.

Perhaps a brief description of A.A.V.S.O. procedure would be of interest. The Association furnishes its members at low cost with blueprint charts drawn on a scale suitable for the equipment to be used, on which the variable is shown as a small dot enclosed in a circle. Many of these charts contain a familiar naked-eye star, which greatly facilitates the finding of the variable in the telescope. The magnitudes of several non-variable stars, corresponding to the variable at different stages, are clearly marked, and the observer has only to compare the variable with two or more of these to form his estimate of its brightness. For example, the variable may appear fainter than a comparison star marked 10.0 but brighter than one marked 10.5. If it appears to be about half way between the two, the estimate would be 10.3. If it appears to be nearer the brightness of the fainter of the comparison stars, it might be estimated at 10.4. With a little training, accurate estimates can be made very quickly.

At the end of each month the observations are listed, showing the name of the variable, its Harvard Number, the Julian date of the observations and the estimated magnitude, and these reports are mailed to Harvard Observatory.

The "Harvard Number" referred to is a very great convenience. Under this system six figures are used to designate each variable, the complete number giving the star's approximate position in the sky, e.g., SS Cygni bears number 213843, which means that its right ascension is 21 hours, 38 minutes, while its declination is 43 degrees north. In the case of southerly declinations, the last two figures are italicized or underlined.

The use of the Julian calendar facilitates the recording and studying of observations, as the days are numbered consecutively regardless of months or years, and the number of days between different observations, even if made over intervals of years, can be found at a glance. Furthermore, the Julian day begins at noon, so that all observations made in a single night are reported under the same date, regardless of whether the observing time extends past midnight. Instructions and tables for converting our calendar to the Julian are provided by the Association.

All reports are acknowledged by post-card, and if any observations are found to be discordant, the observer's attention is drawn

to the error and he is expected to check his work at the first opportunity.

In closing, I would urge any members of the Royal Astronomical Society who possess telescopes, or even good field glasses, to give consideration to becoming variable star observers. The work is extremely interesting and is easily learned, and the observer has the satisfaction of knowing that instead of being an aimless stargazer, he is making a direct and valuable contribution to the science of astronomy. The ranks of the A.A.V.S.O. have been hard hit by enlistments, war work, etc., and any amateur able to spare even two or three evenings a month would be heartily welcomed. Anyone interested should communicate with the Recorder, A.A.V.S.O., c/o Harvard College Observatory, Cambridge, Mass.

582 Mercille Ave., St. Lambert, Que.
August 1st, 1944.

COMMUNICATIONS
FROM THE
DAVID DUNLAP OBSERVATORY
Number 12

THE ORBIT OF THE SPECTROSCOPIC BINARY H.D. 179094

By R. K. YOUNG

THE star H.D. 179094, $\alpha(1900)$ $19^h\ 06^m.1$, $\delta(1900) + 52°\ 16'$, vis. mag. 5.93, Harvard type K0, was discovered to be a binary from four plates taken at this observatory 1939-43. It was noted also that the calcium lines H and K showed as emission lines. An orbit has been determined from the last 35 plates shown in Table I. The first two plates taken with the 12-inch camera were used only in finding the period. The observations in 1942 were made at the Mount Wilson Observatory and the results kindly sent to us here. They check with the period as determined from our own observations. With the exception of the first two plates, all the exposures have been made with one-prism and a 25-inch camera, giving a dispersion of about 33 A per mm. at $H\gamma$. The observations have been made by various members of the staff as indicated in Table I. H, Hogg; Bs, Buscombe; Y, Young; N, Northcott; No, Norris; Ma, Matthews. All the plates have been measured by the writer with the exception of the two 12-inch camera plates for which the results are the mean of several observers.

The spectrum of the star is very similar to that of λ Andromedae. Both stars are listed at Harvard as type K0. Pearce gives the type of λ Andromedae as G6. We would place H.D. 179094 as type G8. Like λ Andromedae it seems to be a sub-giant. No parallax has been published for this star. The intensities of the absolute magnitude lines would make it very similar to λ Andromedae. The calcium lines H and K have about the same strength as in this star. They do not show on all our plates but we have no evidence that they are variable in intensity. The velocities determined for the H and K lines seem to be in substantial agreement with the other lines of the spectrum.

TABLE I

Date G.C.T.	Obs.	J.D. 242-3 +	Phase from T	V_0	O − C
1939—July 28.165	H	9472.665	25.526	+14.3	−5.1
Aug. 5.126	Bs	9480.626	4.897	+31.6	−7.6
1942—July 3.389		0543.889	10.339	− 2.7	−0.3
Aug. 1.314		0572.814	10.665	− 4.1	+1.5
1943—Sept. 20.085	Y	0987.585	25.176	+15.6	+0.7
Oct. 9.996	H	1008.496	17.479	−33.1	+0.3
28.969	H	1027.469	7.880	+15.5	−2.3
Nov. 10.951	N	1040.451	20.862	−17.3	+2.9
13.955	Y	1043.455	23.866	+ 5.6	+1.4
17.958	N	1047.458	27.869	+35.9	−1.7
23.947	Y	1053.447	5.268	+35.3	−1.8
1944—May 17.378	No	1227.878	8.159	+13.7	−1.8
29.353	H	1239.853	20.134	−26.6	−2.0
31.336	H	1241.836	22.117	− 9.2	+1.9
June 8.232	N	1249.732	1.423	+46.1	−0.1
9.238	Y	1250.738	2.429	+47.7	+0.8
11.222	H	1252.722	4.413	+41.1	−0.6
23.242	No	1264.742	16.433	−32.9	+0.7
26.202	Y	1267.702	19.393	−29.8	−1.5
July 3.253	Y	1274.753	26.444	+27.1	−0.2
6.165	N	1277.665	0.766	+44.1	−0.5
11.183	H	1282.683	5.784	+33.8	0.0
14.224	Ma	1285.724	8.825	+ 8.7	−1.1
15.236	No	1286.736	9.837	+ 2.3	+1.1
16.296	No	1287.796	10.897	− 4.0	+3.4
17.238	Y	1288.738	11.839	−11.5	+3.0
18.171	H	1289.671	12.722	−18.9	+1.7
19.133	Y	1290.633	13.734	−25.7	+0.1
21.246	Ma	1292.746	15.847	−33.1	−0.2
Aug. 7.113	Ma	1309.613	4.124	+45.1	+2.2
10.113	Ma	1312.613	7.124	+21.9	−2.1
18.138	Ma	1320.638	15.149	−31.9	−0.6
19.059	N	1321.559	16.070	−34.0	−0.8
20.151	No	1322.651	17.182	−36.0	−2.4
22.121	Y	1324.621	19.142	−28.4	+0.3
Sept. 2.047	N	1335.547	1.468	+45.8	+0.5
3.042	No	1336.542	2.463	+48.5	+1.7
4.035	H	1337.535	3.456	+46.5	+1.3
19.100	No	1352.600	18.527	−34.2	−2.9

The elements published in Table II are the result of a least-square solution. Although the eccentricity is small the solution approximated without difficulty and a small eccentricity seems well established. The probable error of a single plate was 1.1 km. The phases in the curve are numbered from T.

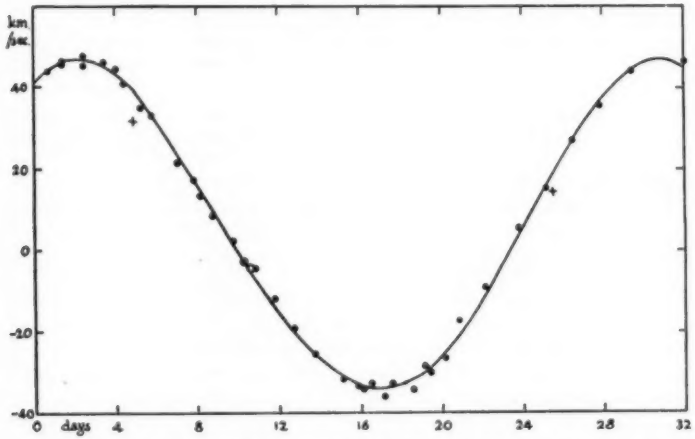

Fig. 1.—The Radial Velocity curve of H.D. 179094. Open circles represent Mount Wilson observations; crosses, D.D.O. 12-inch camera; solid circles D.D.O. 25-inch camera. Phases counted from T.

TABLE II

ELEMENTS OF H.D. 179094

Period	28.59 days	±.01 (estimated)
Periastron passage	J.D. 2431048.179	±.42 days
Semi-amplitude	40.31 km.	±.29 km.
Velocity of system	+5.18 km.	±.25 km.
Eccentricity	.041	±.006
Long. of periastron	330°.1	±5°.5
$a \sin i$	15,800,000 km.	
$\frac{m_1^3 \sin^3 i}{(m+m_1)^2}$	.194 ⊙	

David Dunlap Observatory
Oct. 4, 1944.

OCCULTATIONS: THEIR PREDICTION, OBSERVATION AND REDUCTION

By H. Boyd Brydon

(*Continued from page 336*)

Reduction of the Observations

Of late years the number of occultations observed has increased considerably and amateur computers have been asked to co-operate with their professional brethren to enable reduction to keep pace. On this continent the American Association of Variable Star Observers (A.A.V.S.O.), is actively engaged in the work. Those willing to contribute an hour or two a week to this interesting occupation are urged to do so. They will be cordially received, supplied with computing blanks, interpolation tables and instructions including a completed reduction which serves as a most helpful guide when one is in doubt as to procedure, and will be guided gently along a path of usefulness which, strange to say, becomes remarkably attractive.[23]

Reducing an occultation consists in ascertaining the difference if any between the observed position of the moon at a certain instant and that indicated by lunar theory. The work may be likened to the process of finding a difference of a few ounces between two masses each weighing over a ton, or the cent or two by which two large sums of money are out of balance. Consequently it is the last figure in any quantity which is needed.

The data required for a reduction are the position of the occulted star, the theoretical position of the moon, and the place and time of the observation. The position of the star is now taken from the *Catalogue of 3529 Zodiacal Stars for the Equinox of 1950*, compiled by James Robertson and forming Part II of Volume X of the Astronomical Papers of the American Ephemeris, and generally known as the N.Z.C., New Zodiacal Catalogue. The unknown and variable errors arising from the use of several star catalogues are thus avoided, the positions of the stars are very exactly known and positions of the moon determined from occultations of these stars can be dis-

[23]Enquiries should be addressed to Dr. Alice H. Farnsworth, the Director of the A.A.V.S.O. Occultation Section, Brigham Hall, South Hadley, Massachusetts.

cussed with greater confidence. The theoretical position of the moon's centre is computed from the data in Prof. E. W. Brown's *Tables of the Moon* as arranged in the Almanacs under the heading Moon.[24]

In accord with Bessel's concept, let P, Fig. 15, be the position of an observer as seen from the star, projected on the fundamental plane at the instant when it disappears behind the limb of the oncoming moon M. Then the centre of the moon must be somewhere on the arc AR of a circle whose centre is P and radius PM equal to the moon's radius σ (sigma).

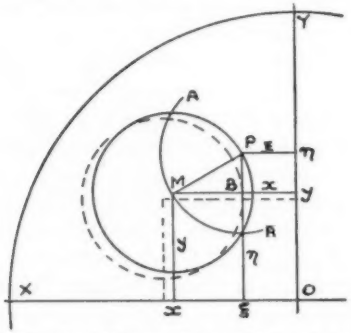

Fig. 15.—Co-ordinates of the centre of the moon, x, y, and of the observer, ξ, η, at the instant of occultation.

At that instant the projected position of P, with reference to the centre O of the earth-circle, is fixed by its coordinates ξ (xi) and η (eta) which are computed from the geocentric latitude, the longitude and the radial distance of P from O. The coordinates x and y of the moon's centre on the fundamental plane are computed from the data in the Almanacs.

[24]For a brief sketch of this great mathematical astronomer see this JOURNAL, vol. 35, p. 43, 1941. His "Theory of the Motion of the Moon" and the accompanying "Tables for computing the Moon's position at any Time," *Memoirs R.A.S.*, 1897-1908, "may be regarded not only as the last word on the subject, but as embodying a seemingly complete and satisfactory solution of a problem which has absorbed an important part of the energies of mathematical astronomers since the time of Hipparchus."—Simon Newcomb, Art. MOON, *Enc. Brit.*

As the figure indicates, if the moon is in its theoretical position, the differences $x - \xi$ and $y - \eta$ form two sides of a right-angled triangle of which the moon's apparent radius σ is the hypotenuse. Since the square on the hypotenuse of a right-angled triangle is equal to the sum of the squares on the other two sides we may write, following Chauvenet, equation (484)

$$(x - \xi)^2 + (y - \eta)^2 = \Delta^2 \qquad (1)$$

"where Δ is the distance of the place of observation from the axis of the shadow."[25]

Substituting σ for Δ and taking the square root we have

$$\sigma = \sqrt{(x - \xi)^2 + (y - \eta)^2} \qquad (2)$$

If the moon is not in its theoretical position but is in some position as shown by the dotted lines, this computation will have a different result, designated σ'. The difference, if any, $\sigma' - \sigma$, between these two quantities is the chief result sought from the reduction of a single occultation.

The basis of the modern method of reducing an occultation is due to R. T. A. Innes, the late Director of the Union Observatory, South Africa. In developing his formulae, Innes[26] was concerned chiefly with ascertaining the departure of the moon from its theoretical position in longitude. He says, *loc. cit.*, "It is assumed that the error perpendicular to the orbit is insensible." Observations of disappearances being sufficient for this purpose, Innes sought to simplify their reduction by changing the positive and negative directions of the moon's coordinates on the fundamental plane, thereby changing the signs of these coordinates while leaving those of the observer unaltered, and rewrote Chauvenet's equation in the form

$$\sigma' = \sqrt{(x + \xi)^2 + (y + \eta)^2} \qquad (3)$$

The change is of doubtful benefit. It gives two meanings to the same direction on the fundamental plane, one applying to the coordinates of the moon, the other to those of the observer. It causes what is really a difference to appear to be a sum. For instance, applying the Innes notation to the conditions represented in Fig. 15,

[25]Chauvenet: *Spherical and Practical Astronomy*, Vol. I, Chap. X, Eclipses.

[26]R. T. A. Innes: "Reduction of Occultations of Stars by the Moon," Astron. Journ., 835, Vol. 35, p. 125, 1924.

x is to be taken as positive and y as negative while ξ remains negative and η positive. Accordingly equation (3) becomes

$$\sigma' = \sqrt{(x - \xi)^2 + (\eta - y)^2} \qquad (3a)$$

This confusion of signs is avoided by using the notation established in theoretical discussion: north and eastward positive; south and westward negative. Following this accepted notation the conditions in Fig. 15 are correctly represented by equation (3b)

$$\sigma' = \sqrt{(-x - \xi)^2 + (+\eta - y)^2}$$
$$= \sqrt{(\xi - x)^2 + (\eta - y)^2} \qquad (3b)$$

Omitting those cases in which the moon's centre and the observer are on opposite sides of the Y-axis, conditions which result in a "graze," there are twelve positions relative to the X- and Y-axes in which a disappearance can occur which affect the signs of the four coordinates and another twelve for a reappearance. The signs of the individual coordinates consequently will depend solely upon the relative positions of the moon and the observer as projected on the fundamental plane.

The precise form of the fundamental equation then is not of great importance but is rather a matter of convenience. The American Ephemeris and the Nautical Almanac in discussing occultations use the form given by Chauvenet (eq. 2). Dr. Brouwer, of Yale University Observatory, under whom the discussion of all reductions made on this continent is carried on, prefers the form of (eq. 3b). In a note to this writer, quoted by his kind permission, Dr. Brouwer says:

"So far as the sum of the squares is concerned, it makes of course no difference whether one uses $(\xi - x)^2$ or $(x - \xi)^2$. However, the angle χ toward the end of the reduction represents the position angle of the star on the moon's limb, and the geometry in the fundamental plane gives

$$\xi - x = \sigma' \sin \chi \; ; \; \eta - y = \sigma' \cos \chi.$$

This is the only reason in my opinion for preferring the difference in that form. In Chauvenet's discussion of the solar eclipse he is interested in the position angle of the moon's centre measured from the centre of the sun. Hence his Q differs from our χ by 180°. And for the discussion of a solar eclipse it is more convenient to use the differences $x - \xi$ and $y - \eta$."

From these considerations it may be desirable to discard the Innes form of the equation (eq. 3), and to adopt the Brouwer form (eq. 3b). Until a revised computing sheet is issued this can be done by changing the signs of the coordinates x and y from positive to negative $-x$ and $-y$ throughout the sheet.

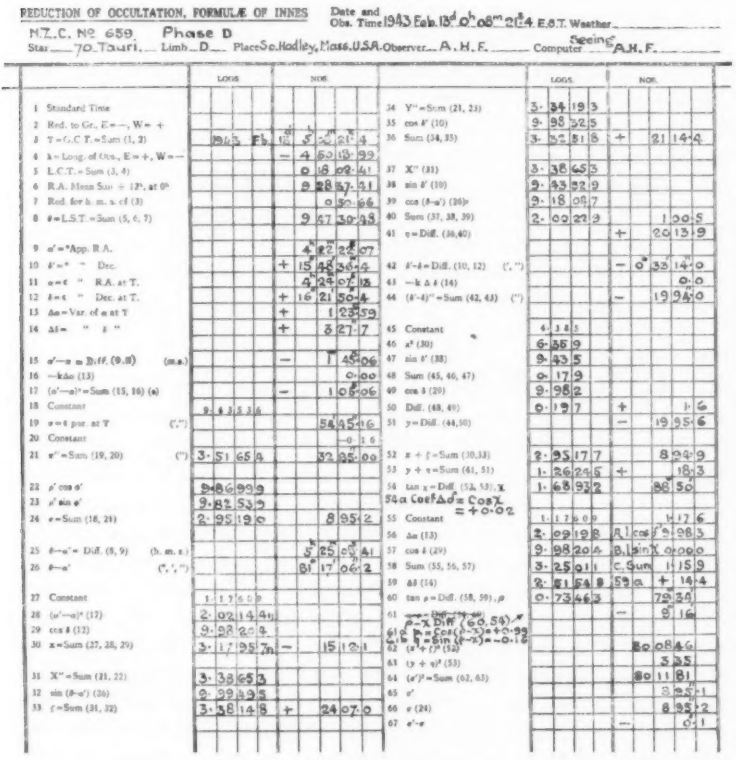
REDUCTION OF OCCULTATION, FORMULÆ OF INNES
Date and Obs. Time 1943 Feb. 13d 0h 08m 20s.4 E.S.T. Weather
N.Z.C. № 659. Phase D
Star 70 Tauri. Limb D. Place So. Hadley, Mass. U.S.A. Observer A. H. F. Computer Keeping A.H.F.
LOGS. NOS.
1 Standard Time
2 Red. to Gr., E = −, W = +
3 T = G.C.T. = Sum (1, 2)
4 λ = Long. of Obs., E = +, W = −
5 L.C.T. = Sum (3, 4)
6 R.A. Mean Sun + 12h at 0h
7 Red. for h. m. s. of (3)
8 θ = L.S.T. = Sum (5, 6, 7)
9 α' = *App. R.A.
10 δ' = * " Dec.
11 α = ☾ " R.A. at T.
12 δ = ☾ " Dec. at T.
13 Δα = Var. of α at T
14 Δδ = " δ "
15 α' − α = Diff. (9, 8) (m.s.)
16 −kΔα (13)
17 (α' − α)" = Sum (15, 16) (s)
18 Constant
19 σ = ☾ par. at T (', ")
20 Constant
21 σ' = Sum (19, 20) (")
22 p' cos φ'
23 p' sin φ'
24 σ = Sum (18, 21)
25 θ − α' = Diff. (5, 9) (h. m. s.)
26 θ − α' (°, ', ")
27 Constant
28 (α' − α)" (17)
29 cos δ (12)
30 x = Sum (27, 28, 29)
31 X" = Sum (21, 22)
32 sin (θ − α') (26)
33 ζ = Sum (31, 32)
34 Y" = Sum (21, 23)
35 cos δ' (10)
36 Sum (34, 35)
37 X" (31)
38 sin δ' (10)
39 cos (θ − α') (26)b
40 Sum (37, 38, 39)
41 y = Diff. (36, 40)
42 δ' − δ = Diff. (10, 12) (', ")
43 −k Δ δ (14)
44 (δ' − δ)" = Sum (42, 43) (")
45 Constant
46 x² (30)
47 sin δ' (38)
48 Sum (45, 46, 47)
49 cos δ (20)
50 Diff. (48, 49)
51 y = Diff. (44, 50)
52 x + ξ = Sum (30, 33)
53 y + η = Sum (41, 51)
54 tan χ = Diff. (52, 53). χ
54a Coef Δσ = Cos χ = +0.02
55 Constant
56 Δα (13)
57 cos δ (29)
58 Sum (55, 56, 57)
59 Δδ (14)
60 tan ρ = Diff. (58, 59). ρ
61 ρ − χ Diff (60, 54). π
61 ζ = Sin (θ − α') = −0.18
62 (x² + y²) (52)
63 (y + η)² (53)
64 (σ')² = Sum (62, 63)
65 σ'
66 σ (24)
67 σ' − σ

Fig. 16.—Sample Reduction.

The present computing sheet, Fig. 16, differs from the original by the addition of several items. These reduce considerably the time and labour needed to determine the true position of the moon by analysis and discussion of groups of occultations. In the figure

the signs of x and y are in the form given by Innes (equation 3a).[27]

While lengthy, when taken apart and the object and meaning of the several steps are comprehended, the computing sheet will be found by no means so formidable as it looks. Except that in a reduction precise instead of approximate data are used and the work is done with logarithms, several of the computations will be recognized as similar to the formulae underlying the graphic method of prediction.

It is no exaggeration to say that after some practice anyone having a working acquaintance with logarithms and trigonometric functions can complete a reduction in a few hours. Indeed, because the whole reduction can be completed in a mechanical manner without the meaning of a single step in the process being known, there is danger that a mistake made early in the work may remain undetected until the reduction is nearly finished. It is hoped that the discussion which follows will assist the inexperienced computer to recognize promptly an erroneous quantity.

Most errors in computing arise from a mistake in the sign of some quantity, especially of trigonometric functions. The sign + should be placed before every positive quantity as well as − before every negative quantity. Logarithms of negative quantities must be indicated by the suffix n. Thus log − 4 is $0{\cdot}60206_n$. Errors in the signs of trigonometric functions can be avoided if a chart such as Fig. 17 be pasted inside the front cover of the tables and referred to when there is the slightest doubt as to the correct sign. Some notes on the signs of quantities in the reduction are included here.

The data heading the computing sheet must be stated by the observer whether or not he reduces the observation. His position, the date, time and phase observed are essential. Longitude and latitude are required to the nearest second of arc and altitude above mean sea level to within 500 ft. To save the time of the computer the observer should compute, record and furnish his geocentric coordinates—see below. The phase observed is to be marked D for a

[27] These changes and additions are described in a paper by Dr. Farnsworth which appeared in *Pop. Ast.*, vol. 51, 1943. See particularly p. 441ff. For a reproduction of the original sheet and an excellent explanation of the reduction process according to Innes, see L. S. Barnes, "A Graphic Interpretation of the Occultation Formulae," *Pop. Ast.*, vol. 37, p. 120, 1929.

disappearance, R for a reappearance; the limb concerned D or B as it was dark or bright. The optical equipment and power used; the weather, clear, windy, misty, etc., and the quality of the seeing, steady, unsteady should be noted also by the observer.

Item 1. This is the observer's standard time of the observation. It should be recorded at least to within half a second. In professional work the time is usually stated to the nearest tenth of a second.

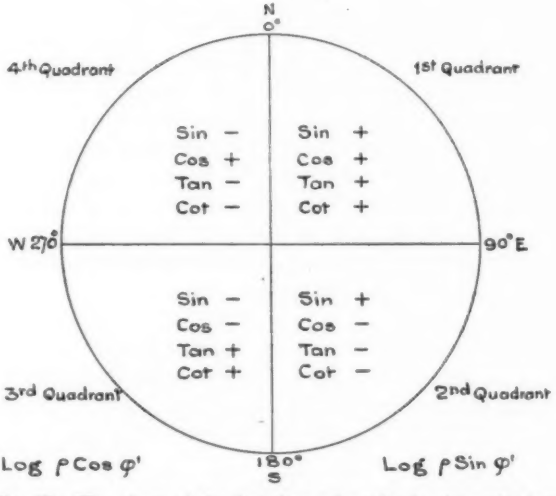

Fig. 17.—The signs of the functions of angles in the reductions of occultations.

Item 2. Is the mean time difference from Greenwich of the observer's standard time meridian. Added to item 1 if west or subtracted if east, the result is T, item 3, the Greenwich Mean Time of the observation. The computing sheet terms this Greenwich "Civil" Time. The term "Mean" Time being definite is to be preferred.

The day of the month is a part of this item. At Greenwich the day may be that preceding or following the day of the month at the place of observation, depending upon its longitude. Suppose the place is 6 h. west of Greenwich and the time 10.00 p.m. standard

time or 22 hours on December 31, 1943. The corresponding time at Greenwich is 4 h. January 1, 1944. Thus the reduction to Greenwich may change the day of the month, the month and the year.

Item 4 is the longitude of the observer east or west of Greenwich expressed in time. *Item* 5, L.C.T., local civil time, is the local mean time at the observer's position corresponding to the Greenwich mean time T, not his "daylight" or standard time.

Item 6, Right ascension of the mean sun plus 12 h. at $\mathring{0}$ h., is the sidereal time at 0 h. of the same Greenwich date as was found for item 3. The sidereal time at 0 h. G.M.T. is given for every day in the almanacs on the left hand of the two pages headed "Sun" first following the Calendar. *Item* 7, reduction for the hours, minutes and seconds of T, item 3, is the amount by which sidereal time gains on mean time during the interval from 0 hours to the time T. It is obtained from Table III in the American Ephemeris or the Nautical Almanac. The sum of items 5, 6 and 7, is no. 8, θ, (theta), the sidereal time of the observation at the observer's position corresponding to the mean time instant T, item 3. T is thus fundamental to the reduction. An error in T vitiates the whole.

Items 9, α', and 10, δ', are the apparent right ascension and declination of the occulted star. They are taken directly from the data for the occultation given in the Elements of Occultations in the almanacs and should be checked to insure that they are correctly copied.

With *items* 11 to 14 which define the theoretical position and direction of the moon's motion and *item* 19, the moon's parallax, the most troublesome part of a reduction is reached: interpolation of the values of these five quantities for the instant T of the observation from the data given in the almanacs.

When the difference, d_1, between consecutive tabular values, f_0, f_1, etc., of a quantity is constant, as for instance the constant hourly difference in the distance of a steadily moving train from its starting point, the interpolation necessary to find its distance at a time some fraction n of the interval beyond some point f is a simple matter. It is the value at f plus the fraction n of the tabular difference d, or

$$f_n = f + nd_1 \tag{4}$$

When, however, the tabular difference d_1, the "first" difference, is not constant, as when the speed of the train is varying, "second" differences, d_2, the differences between successive first differences, must be taken into consideration. This is the condition met with when reducing the tabular values of the moon's right ascension and declination, items 11 and 12; the hourly changes therein, items 13 and 14; and the moon's parallax, item 19, to their values at the instant T of the observation.

Since these second differences themselves will not be constant, the closer the required instant is to a tabular value the less will be the correction for that inconstancy and the smaller will be the residual error. The required value therefore is computed from the nearer of the two tabulated values between which the instant lies; going "forward" or down the table when the required value is nearer the previous value and "backward" or up the table when it is nearer the succeeding value.

In such cases the interpolation formula becomes

$$f_n = f \pm nd_1 + S \qquad (5)$$

where f is the nearest tabulated value; the upper sign $+nd_1$ being used in forward interpolation, the lower $-nd_1$ when interpolating backward. Since no point can be more than one half of the interval from f, n, the fraction of the interval, can never be more than 0·5 and is always positive. If then the product nd_1 is negative, the first difference d_1 must be negative, that is, the difference between successive tabular values is decreasing.

The contribution of the second difference S to the required value of the quantity can be computed from the equation

$$S = -0{\cdot}5n(1-n)d_2 \qquad (6)$$

but is more conveniently taken from interpolation tables prepared for the purpose. Depending upon the form of the table, d_2 in this equation is either the mean of the second differences, $\frac{d_2' + d_2''}{2}$, immediately preceding and following d_1 as in the tables furnished to computers by the A.A.V.S.O., or the sum $d_2' + d_2''$, as in the more usual form of such tables as Table XVII "Second Difference Cor-

rection" in the Nautical Almanac (1943, p. 570). Provided that the form of the table be complied with either can be used.[28]

The values of d_2 given in such tables are whole numbers ending in 0, 5, or multiples of 25. The second differences of the quantities for which interpolation is required, however, contain fractions: in right ascension and parallax two places of decimals and in declination, one place. Accordingly, before entering the tables these fractions must be removed by multiplying d_2 by 100 in the first two cases and by 10 in the third. The product is then rounded off to conform with the above end figures of the tabulated quantities. In turn, the values of S' taken from the table must be divided by the original multiplier to reduce them to the values to be used in the interpolation.

When second difference corrections are needed in the interpolated values of a quantity the two tabular values immediately preceding and the two immediately following the date T must be taken from the Moon tables in the almanac.

All differences are formed by subtracting the earlier tabulated value from the next following.

The signs of quantities in an interpolation can be checked by the following:

n is always positive. nd, has the same sign as d_1.
When d_1 is increasing, d_2 has the same sign.
When d_1 is decreasing, d_2 has the opposite sign.
The sign of S is always opposite to the sign of d_2.

The foregoing brief summary of the mechanics of interpolation is illustrated by computing the interpolated values of items 11, α ; 12, δ, the moon's right ascension and declination; 13, $\Delta\alpha$ and 14, $\Delta\delta$, the hourly changes in those quantities and 19, π, the moon's parallax for the times specified. It is convenient to compute them in the order 11, 13, 12, 14, 19. For items 11, 13 and 19 the formula to be used is equation 5; for items 12 and 14, equation 7.

$$f_T = \begin{cases} d_1 + (h - \cdot 50)d_2 \text{ when } d_2 \text{ is the mean} \\ d_1 + \cdot 5(h - 50)d_2 \text{ when } d_2 \text{ is the sum} \end{cases} \qquad (7)$$

where f_T is $\Delta\alpha$ or $\Delta\delta$ at the time T, h is the fraction of one hour

[28]See "Interpolation and Allied Tables," H. M. Stationery Office, London, price one shilling. For the theory of interpolation see Rice: Theory and Practice of Interpolation.

represented by the minutes and seconds of T. In forward interpolation h equals n, the fraction from the beginning of the hourly interval; in backward interpolation h equals $1 - n$, the fraction from the end of the interval; d_1 and n have the same meanings as in equation 4, and d_2 as shown above has the meaning required by the interpolation table which is being used.

Now for the examples.

1. Required the moon's right ascension, α, item 11, and $\Delta\alpha$, item 13, its change per hour at the date T, 1943 April $14^d\ 16^h\ 13^m\ 16^s.2$.

Item 11. From the tables of the moon in the almanac take out the moon's right ascension and the hourly change for the two hours on each side of the date T. Find d_2' and d_2'' and take their sum or their mean as required for the interpolation table being used.

			R.A.	d_1	d_2
H	h	m	s	s	s
15	9	10	56·24		
				+ 121·42	
16	9	12	57·66		− 0·05 = (d_2')
				+ 121·37	
17	9	14	59·03		− 0·07 = (d_2'')
				+ 121·30	
18	9	17	00·33		
			Sum.....		− 0·12
			Mean.....		− 0·06

Interpolation: forward. Formula $f_n = f + nd_1 + S$.

Interval: 1 hour. d_1 positive $= + 121{\cdot}37$

$n = 13^m16{\cdot}2^s = 796{\cdot}2/3600^s = + 0{\cdot}22117$

$nd_1 = + 0{\cdot}22117 \times (+ 121{\cdot}37) = + 26{\cdot}843^s$

Rounding off n to 0·22, the nearest hundredth, and $d_2' + d_2''$ (multiplied by 100) to the nearest multiple of 5, here 10, Table XVII of the Nautical Almanac is entered and S is found to be 1, which divided by 100 equals 0·01 and is positive since d_2 is negative. Then

	h	m	s	
at 16h $\alpha_{\mathbb{C}}$ =	9	12	57·66	
+ nd_1 =			+ 26·84	
+ S =			+ 0·01	
Sum.....	9	13	24·51	= $\alpha_{\mathbb{C}}$, the right ascension of the moon at time T.

Item 13 $\Delta\alpha$. Interpolation forward.

Formula: $f = d_1 + \cdot5(\mathrm{h} - \cdot50)d$.

where $d_2 = d_2' + d_2'' = -0\cdot12$; $h = n$

$0\cdot5(h - \cdot50) = \cdot5(n - \cdot50) = 0\cdot22117 - \cdot50)/2 = -\cdot14$

$0\cdot5(\mathrm{h} - \cdot50)d_2 = +0\cdot0168$; rounded off $= +0\cdot02$

Then	d_1 =	$+121\cdot37$
	$\cdot5(\mathrm{h} - \cdot50)d_2$ =	$+\quad\cdot02$
	Sum.... =	$+121\cdot39 = \Delta\alpha$.

the hourly change in the moon's right ascension at the time T.

2. Required the moon's declination δ, item 12, and its hourly change $\Delta\delta$, item 14, for the time 1943 May $16^{\mathrm{d}}\ 14^{\mathrm{h}}\ 39^{\mathrm{m}}\ 21\cdot3^{\mathrm{s}}$.

Item 12. From the tables of the moon take out:

H	Declination			d_1	d_2
13	$-1°$	05′	36″0		
				$-665''4$	
14	-1	16	41·4		$-0\cdot4$
				$-665\cdot8$	
15	-1	27	47·2		$-0\cdot5$
				$-666\cdot3$	
16	-1	38	53·5		
				Sum.....	$-0\cdot9$

Interpolation backward. Formula: $f_n = f - (nd_1) + S$.

Interval 1 hour, d_1 negative $= -665\cdot8$

$n = (60^{\mathrm{m}} - 39^{\mathrm{m}}21\cdot3^{\mathrm{s}}) = 20^{\mathrm{m}}38^{\mathrm{s}}\cdot7 = 1238\cdot7/3600 = +0\cdot34408$

$-nd_1{}^{\mathrm{s}} = -(0\cdot34408 \times -665\cdot8) = +229''4 = +3'\ 49''4$.

Rounding off n to 0·34 and $d_2 = \cdot9 \times 10$ to 10, Table XVII is entered and S found to be 1, which divided by 10 is 0·1, and is positive because d_2 is negative.

Then at 15h	$\delta_{\mathbb{C}}$ =	$-1°\ 27'\ 47''\cdot2$
	$-nd_1$ =	$+\quad 3\ \ 49\cdot4$
	$+S$ =	$+\qquad 0\cdot1$
	Sum..... =	$-1\ 23\ \ 57\cdot7 = \delta_{\mathbb{C}}$

the moon's declination at the time T.

Item 14. $\Delta\delta$ Formula: $f_n = d_1 + \cdot5(\mathrm{h} - \cdot50)d_2$.

$d_1 = -665''\cdot8$; $h = 1 - n = +0\cdot65592$; $d_2 = -0\cdot9$

$\cdot5(\mathrm{h} - \cdot50)d_2 = \cdot5 \times +\cdot65592 \times -0\cdot9 = -0\cdot295$

$= -0\cdot3$

Then at 15 hours Δ_δ = − 665·8
·5(h −·50)d_2 = − ·3
Sum..... − 666·1 = $\Delta\delta$, the hourly change in the moon's declination at the time T.

3. *Item* 19. Required the moon's parallax π for the date 1943 July $15^d\ 19^h\ 23^m\ 41^s{\cdot}3$.

The moon's parallax is given at half-day intervals in the almanacs. The nearest half-day to the date being July 16·0 the interpolation goes backward. The formula, equation 5, thus becomes:

$$f_T = f - nd_1 + S,$$

where $n = (24^h - 19^h\ 23^m\ 41^s{\cdot}3)/12 = 4^h\ 36^m\ 18^s{\cdot}7/12$
and can be taken from Table V of the Nautical Almanac; "Conversion of hours, minutes and seconds into decimals of a day," by setting down the decimals given therein and doubling the sum.

$4^h\ 36^m$ = 0·19167
18^s = ·00021
$0{\cdot}7^s$ = ·000008
0·191888 × 2 = 0·38378

From the tables of the moon take out:

	H		π	d_1	d_2
July	15·0	60′	20″43		
				+ 22·94	
	15·5	60	25·37		− 3·20
				+ 19·74	
	16·0	60	45·11		− 3·83
				+ 15·91	
	16·5	61	01·02		
			Sum.....		− 7·03

$d_1 = 19''{\cdot}74$; $d_2 = -7''{\cdot}03$

Multiplying by 100 to remove fractions and rounding off, $d_2 = -705$.

$$-nd_1 = -(\cdot 38378 \times +19{\cdot}74) = -7{\cdot}59$$

The value of S for 705 is obtained from Table XVII by taking three times the value for $d_2 = 200$ plus the value for
$d_2 = 105$ or $12 \times 3 + 6 = 42/100 = 0{\cdot}42$.
Since d_2 is negative S is positive.

Then we have

July 16·0	π	=	+ 60′	45·11
	$-nd_1$	=	−	7·58
	$+S$	=	+	·42
	Sum.....		60	37·95 = π, item 19, the moon's parallax for the date.

N.B.—To facilitate checking the reduction, it is requested by

the A.A.V.S.O. that the work sheets for all interpolations be enclosed with the completed blank.

Let the parallax π of the moon in seconds of arc as found from the last example be the angle CMS or arc CAR in Fig. 18, where M is the centre of the moon, C that of the earth, E, CM or R their centre to centre distance and r the earth's equatorial radius. Then

$$\sin \pi = r/R = \sin CMS = \sin CAR ;$$

or putting R equal to unity, $\sin \pi = r''$ (8)

The sign of sin π is always positive.

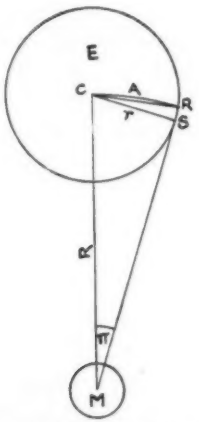

Fig. 18.—Relation of sine to arc, Item 20.
The angle CMR is about 17 times the actual size.

Since the arc CAR is small, about 1°, the difference between it and its sine, CS or r, is always small. Further, as the range in the value of the moon's parallax is very small, this difference varies so slightly that without appreciable error it can be taken as constant at its average value $0{\cdot}16''$ for all values of π. Deducting this quantity, item 20, from item 19 we have item 21, the earth's radius r expressed in seconds of arc.

Having item 21, the first major objective of the reduction, σ, item 24, the moon's radius r_m expressed in seconds of arc is reached by the simple proportion:

$$r_m : r = \sigma'' : r'' \tag{9}$$

whence as $r_m = 0{\cdot}2725r$ and $r = \sin \pi$

$$\sigma = 0{\cdot}2725 \sin \pi \tag{10}$$

or, taking logarithms,

$$\log \sigma = \log 0{\cdot}2725 + \log \sin \pi \tag{11}$$

item 24 = item 18 + item 21.

Returning to items 15 and 16. Item 15, $\alpha' - \alpha$, is the difference between the right ascensions of the star and the centre of the moon at the time T. It is arranged that this difference shall be so small

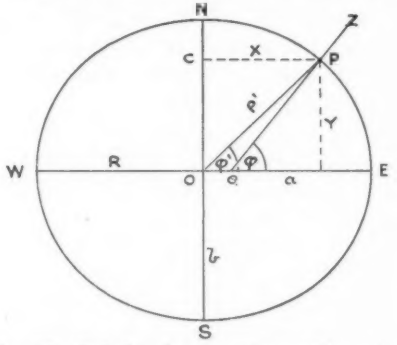

Fig. 19.—Relation between geographic and geocentric latitude.
The flattening $(a-b)/a$ shown is about 30 times the actual amount.

as practicable by applying to it a correction k, item 16. A similar correction, item 43, is also applied to $\delta' - \delta$, item 42, their difference of declination. These corrections, adjusted at suitable intervals, compensate for known discrepancies between the actual and theoretical positions of the moon and irregularities in the speed of rotation of the earth, with the result that $\sigma' - \sigma$ is confined to an amount which does not exceed three to four seconds of arc. The amount of the correction is published annually in the almanacs.

Items 22 and 23. In predicting an occultation the earth is assumed to be a sphere of radius R equal to unity. Reduction being based upon the true figure, an oblate spheroid, the co-ordinates of the observer's position must be corrected from his geographic to his geocentric position, his latitude from ϕ to ϕ', and his centre distance

from R to ρ' which must include his altitude above sea level. His longitude is not affected by the change.

The relationships between R and ρ' and between Q and ϕ' are indicated in Fig. 19. Let $NESW$ be a section of the earth taken on the meridian of a place P. NS is the earth's axis, EW the trace of the plane of the equator and O the centre. Z is the zenith of the place P. The angle EQP is the geographic latitude ϕ of the place and the angle EOP the geocentric latitude ϕ'. In the figure the difference between these latitudes is of course greatly exaggerated. Actually the difference is zero at the equator and the poles and reaches a maximum of about 11′ 36″ at about latitude 45°. The standard symbol for the geocentric radius is ρ. The computing sheet uses ρ' to avoid possible confusion with ρ the symbol for the direction angle of the moon's motion.

Neglecting the altitude of the place above mean sea level, were the earth a sphere the distance of P from the polar axis NS would be $R \cos \phi$, where R is unity. Actually it is $\rho \cos \phi'$, X, Fig. 19, where ρ is the length of the geocentric radius OP in terms of the equatorial radius OE. Thus $\rho \cos \phi'$ is the radius of the observer's circle of geocentric latitude. Similarly, $\rho \sin \phi'$, Y, is the geocentric distance of the plane of that circle from the plane of the equator.

These important constants, $\rho \cos \phi'$ and $\rho \sin \phi'$, are required in all occultation reductions. They should be entered for ready reference in the diagram of signs of the trigonometric functions, Fig. 17.

The formulae for computing $\rho \cos \phi'$ and $\rho \sin \phi'$ usually apply only to places at mean sea level. Among them are:

$$\tan \phi' = \frac{b^2}{a^2} \tan \phi \qquad (12)$$

where by the Hayford spheroid of 1909

a, the equatorial radius = 6378·39 km.
b, the polar radius = 6356·91 "

whence $\tan \phi' = 0{\cdot}99326 \tan \phi$.

For computing ρ we have

$$\rho = a \sqrt{\frac{\cos \phi}{\cos (\phi - \phi') \cos \phi'}} \qquad (13)$$

where a, the equatorial radius, is taken as unity and ρ is found as a fraction of that radius.

(To be concluded)

THE STARK EFFECT OF HELIUM IN SOME B-TYPE STARS

By Anne B. Underhill and Wm. Petrie

SOME years ago a rather anomalous broadening of the HeI diffuse series triplet line λ4471 became apparent, when attempts were made to establish the presence of Stark Effect in the spectra of dwarf B-type stars by means of the broadened helium diffuse series lines. Several hypotheses have been put forward to explain this feature, but because of lack of data on the intensities of helium lines in B-type spectra it has not been possible to check these theories. The purpose of this investigation is to provide line intensity data by careful measurements of the profiles of helium lines on high dispersion plates. Six typical B-type stars with strong helium lines have been selected for study.

When a radiating atom is placed in an electric field, the normal spectrum of that atom is altered. The normal lines are displaced from their zero-field position and also new lines may appear in the spectrum. This Stark Effect, as it is called, is most pronounced in the spectra of hydrogen and helium, although high dispersion laboratory spectra of other elements show the effect to a lesser degree.

In stellar spectra the Balmer lines of hydrogen and the diffuse series lines of HeI are the only lines appreciably affected by electric fields. The fluctuating fields set up in the atmosphere of a dwarf star by the density of charged particles are considered to be of the order of $10^3 - 10^4$ volts/cm., and cause a displacement of the $2p - nd$ lines of HeI towards the red. This displacement is small for the leading numbers of the diffuse series, but increases with serial number. These fields also permit the appearance of the forbidden or electric combination lines $2p - 4f$, $2p - 5f$, etc. The electric combination lines, which lie to the violet of the corresponding d line, are the chief cause of broadening of the violet wings of the diffuse series lines. These lines are displaced to the violet with increasing electric fields, although a displacement to the red may take place until fields of 30 kv./cm. are reached. The intensities of these lines as well as their position depend upon the strength of the electric field. Since in a stellar atmosphere the electric fields are fluctuating,

the effect of all possible positions and intensities of the lines is observed, and the net result is an asymmetrical broadening of the helium diffuse series lines. No electric combination lines can appear close to the $2p - 3d$ lines (singlets or triplets), hence the leading members of the series are not broadened by Stark Effect, but only displaced very slightly. Appreciable electric fields can only be set up in the comparatively dense atmospheres of dwarf and intermediate stars. The low density in the atmosphere of a giant star produces weak electric fields, hence Stark Effect is negligible. Stark broadening then is found in the spectra of dwarf and intermediate stars, but not in spectra of giant stars.

Quantitatively, the broadening of the HeI diffuse series lines in spectra of dwarf and intermediate stars has been explained[1] by Foster and Douglas by Stark effect as outlined above. However, there seems to be an anomalous absorption near the zero field position of the $2^3P - 4^3F$ line, λ4470 and $2^1P - 4^1F$ line λ4920.

One explanation of the anomalous absorption near λ4471 in dwarf and intermediate stars was suggested by Struve[2] in 1938. He accounted for the extra absorption by means of a damping constant which is about twenty times the value for ordinary lines, and which depends upon the sensitivity of the line to Stark effect. Since Stark broadening has little effect upon the leading member of the series, this member should show little or no extra absorption. In giant stars, there should be no marked difference in the damping constant from its ordinary value owing to the absence of electric fields.

In 1939 Foster and Douglas[3] analyzed helium line profiles in the stars ιHerculis and γPegasi, attempting to account, both quantitatively and qualitatively, for the observed broadening of the HeI diffuse series lines. Near λ4922 and λ4471, they found absorption which could not be explained by pure Stark effect, or by likely blends. This absorption in each case totalled about 30% of the line. To explain this absorption Foster and Douglas considered a possible cycle as indicated in figure 1 and reasoned as follows:—If stellar conditions are such as to give diffuse lines 3 angstroms or more wide, and there is a reasonable departure from the Boltzmann distri-

[1] *Monthly Notices*, vol. 99, p. 150, 1939.
[2] *Observatory*, vol. 61, p. 53, 1938.
[3] *loc. cit.*

bution, a broadening of the $4D$ level might be expected. When radiation characteristic of the zero-field position of the electric combination line $2p - 4f$ is considered, events in the direction indicated are more probable than in the reverse direction. Thus, even if there were no fields present to produce the f line (this could not be so, since conditions giving rise to the broadened levels would also give rise to electric fields) there would be relatively strong $2p - 4d$ absorption in the region of the f line, since emission accompanying the absorption will be relatively weak here owing to a leakage $4d \rightarrow 4f \rightarrow 3d \rightarrow 2p$. In varying fields it would be expected that the $2p - 4f$ line be augmented at zero-field positions with its max-

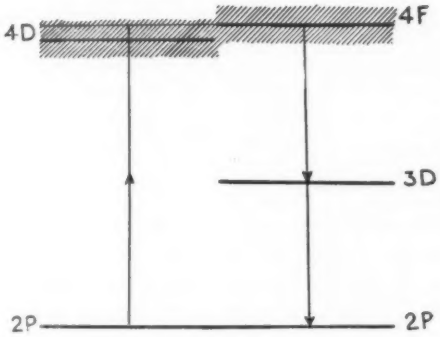

FIG. 1

imum intensity shifted toward the d line, and there should be no sharp distinction between the lines.

This absorption is thus a secondary maximum in the d absorption and its existence is not proof that electric fields exist in stellar atmospheres. That such fields do exist, however, is evident from the greatly extended Balmer wings, and the broadened wings of the sharp series and diffuse series HeI lines.

Due to this leakage, the lines $3d - 4f$, and $2p - 3d$ are weakened by emission more than is the case in a normal star, i.e., any star in which conditions are not likely to make such a cycle possible. These conditions are most likely to be met in a dwarf or intermediate star, but not in a giant.

In the same year Goldberg[4] considered the problem of the large absorption near λ4471. He showed that electric fields in dwarf and intermediate stars are strong enough to account for the observed absorption of the electric combination line λ4470. He did not consider what displacement of λ4470 would occur because of these fields, but calculated that the observed absorption could be quantitatively explained by Stark absorption. He did not consider the effect on any other of the diffuse lines.

Observational Material

TABLE 1—STARS STUDIED

Star	HD No.	m_v	Spectral Type	Luminosity Type
γPegasi	866	2.9	$B2.5_{ss}$	intermediate
ρLeonis	91316	2.9	$B1.0_s$	giant
ηUrsae Majoris	120315	1.9	$B5.0_{nn}$	dwarf
ιHerculis	160762	3.8	B3.5	intermediate
67 Ophiuchi	164353	3.9	$B5.0_s$	giant
55 Cygni	198478	4.9	$B3.0_{ae}$	giant

Intensity measurements were made by Dr. R. M. Petrie to verify the spectral classification by Williams.[5]

The plates were taken at the Dominion Astrophysical Observatory by various members of the staff. Most of the material was calibrated for intensity work by the rotating sector now in use at that institution, although a few of the older plates were calibrated by the neutral tint wedge which was in use at that time. Line profiles were obtained and equivalent widths derived by the usual methods. Measurements were made for the HeI diffuse series lines λλ6678, 5876, 4922, 4471, 4388, 4144, 4026, 3820.

The mean equivalent width for each line together with the number of plates used are given in tables 2 and 3.

From a consideration of figure 2, which give a plot of serial number against equivalent width for lines of the diffuse series of helium, a difference between giants, intermediates, and dwarfs is at once apparent. In the giants, ρLeonis, 55 Cygni, 67 Ophiuchi, the first member of both the singlet and triplet series is the strongest

[4] *Astroph. Jour.*, vol. 89, p. 623, 1939.
[5] *Astroph. Jour.*, vol. 83, p. 305, 1936.

TABLE 2—MEAN EQUIVALENT WIDTHS (GIANTS)

	ρLeonis		55 Cygni		67 Ophiuchi	
	No. of Plates	E.W.	No. of Plates	E.W.	No. of Plates	E.W.
6678.....	1	1.02	3	1.00	2	1.16
4922.....	3	.47	1	.64	5	.74
4388.....	3	.36	4	.49	5	.41
4144.....	3	.30	2	.43	6	.45
4009.....	3	.21	4	.30	6	.34
5876.....	3	1.19	3	.83[6]	2	.97
4471.....	3	.71	3	.74	6	.73
4026.....	3	.51	5	.62[7]	6	.64
3820.....	3	.33	3	.56	3	.65

TABLE 3—MEAN EQUIVALENT WIDTHS (DWARFS)

	γPegasi		ιHerculis		ηUrsae Majoris	
	No. of Plates	E.W.	No. of Plates	E.W.	No. of Plates	E.W.
6678.....	2	.55	4	.47	3	.54
4922.....	5	.96	7	.91	4	.85
4388.....	8	.82	24	.64	5	.70
4144.....	8	.79	8	.62	4	.66
4009.....	8	.55	8	.44	5	.43
5876.....	2	.77	4	.61	3	.80
4471.....	8	1.28	25	1.07	5	1.01
4026.....	8	1.25	7	1.02	5	1.28
3820.....	3	1.14	5	.93	3	.60

line of the series, and the intensities of the lines decrease with increasing serial number.

In the intermediate and dwarf stars, γPegasi, ιHerculis, ηUrsae Majoris, the first member of each series is one of the weakest lines measured, the second member being much stronger. Stark effect broadens the second and succeeding members but does not affect the first member. The first member should have therefore the same

[6]5876 is possibly weakened by emission in 55 Cygni and 67 Ophiuchi. 55 Cygni is classed as an emission line star.

[7]The helium sharp series line λ4024 has been subtracted from the measured profiles of λ4026 in the giant stars 55 Cygni and 67 Ophiuchi.

[8]In ηUrsae Majoris the wings of $H\eta$ and $H\theta$ overlap owing to the great broadening of the profiles by the rapid rotation of the star and development of Stark wings. The height of the continuous spectrum probably was drawn too low for λ3820 because of this overlapping.

relative strength as in a giant star of the same spectral class or one of the slightly earlier class. That this is not the case is evident.

When the various hypotheses put forward to explain the relatively large absorption near the second member of the singlets, λ4922, and of the triplets, λ4471, are considered, it is seen that a weakening of λ6678 and λ5876 is a direct consequence of the cycle proposed by Foster and Douglas.

The intensity of an absorption line is a function of the number of atoms absorbing and emitting at a given wavelength. If some effect, apart from the general equilibrium, causes extra emission or absorption, the line will be strengthened or weakened accordingly. Such a departure from the general equilibrium occurs in the leakage cycle proposed by Foster and Douglas. Energy is absorbed at λ4470 owing to level broadening, and is re-emitted at λ5876, thus weakening the absorption line at this wavelength.

From the explanations of Struve and Goldberg one cannot infer a weakening of the leading members of the singlet and triplet series. Moreover, the observed weakening of λ6678 and λ5876 cannot be due to emission as ordinarily considered in emission line stars, for then it should be more noticeable in giant than intermediate or dwarf stars. It is, therefore, concluded that the observed weakening of the leading members, relative to the other lines of the diffuse series, is strong evidence in favour of the cycle suggested by Foster and Douglas.

A consideration of figure 2 shows that in most cases the equivalent widths for λ4144 and λ4026 are above the smooth curve. It seems likely that the deviation in λ4144 is due to blending with lines of a SII multiplet, as the strongest lines of the multiplet can be seen on high dispersion plates. By measuring the intensities of these lines, and assuming that the relative intensities of the lines causing the blend to the intensities of the measured lines of the multiplet are the same as given by C. E. Moore,[9] an estimate of the blending effect is made. When such a correction is applied the curve becomes much smoother.

The only obvious line blending with λ4026 is the 2^1P-7^1S HeI line λ4024. In high dispersion spectra of the giant stars 55 Cygni and 67 Ophiuchi, this line is seen to be distinctly separated from λ4026. By measuring the intensities of the preceding members in

[9] A Multiplet Table of Astrophysical Interest.

the series and proceeding as above, allowance is made for the blending produced by λ4024. In dwarf and intermediate stars there is much complex structure in this region owing to the appearance of electric combination lines.

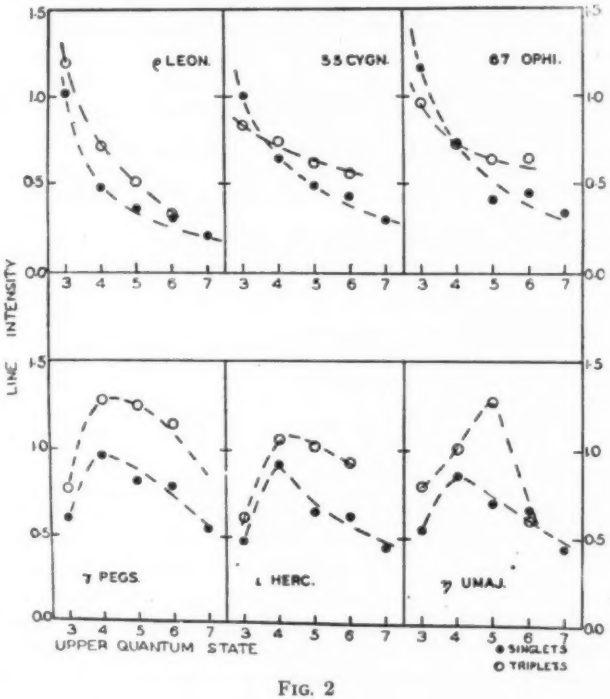

FIG. 2

Foster and Douglas in their analysis of the HeI diffuse series lines in ιHerculis and γPegasi, estimate that the leakage at λ4922 and λ4471 amounts to about 30 per cent. of the total line. Since some of this energy is emitted again at λ6678 and λ5876, we can calculate the change produced in the equivalent width of these lines. If the continuous spectrum is produced by black body radiation it is possible to calculate the change in equivalent width at λ6678 for a given change at λ4922. Interpolation from the work of Panne-

koek[10] shows that with *B* type stars in the wavelength range used, no appreciable error is introduced by this assumption of black body radiation.

If there are N transitions involved in the leakage absorption at wavelength λ_1, then the energy absorbed is

$$Nh\nu_1 = Nhc\lambda_1^{-1} = 8\pi ch\lambda_1^{-5}(e^{\frac{ch}{\lambda_1 kT}} - 1)^{-1}W_1 \qquad (1)$$

giving

$$N = 8\pi\lambda_1^{-4}(e^{\frac{b}{\lambda_1}} - 1)^{-1}W_1 \qquad (2)$$

where $b = \frac{ch}{kT}$ since for a given star T is constant.

There are also N transitions emitting energy at λ_2, hence

$$Nh\nu_2 = Nhc\lambda_2^{-1} = 8\pi ch\lambda_2^{-5}(e^{\frac{ch}{\lambda_2 kT}} - 1)^{-1}W_2 \qquad (3)$$

giving

$$N = 8\pi\lambda_2^{-4}(e^{\frac{b}{\lambda_2}} - 1)^{-1}W_2 \qquad (4)$$

equating (2) and (4) and transposing

$$W_2 = \left(\frac{\lambda_2}{\lambda_1}\right)^4 \frac{e^{\frac{b}{\lambda_2}} - 1}{e^{\frac{b}{\lambda_1}} - 1} W_1 \qquad (5)$$

To evaluate the constant b, T is taken as 20,000°.

Actually the leakage need not be very great to have an appreciable effect on the intensities of λ6678 and λ5876. From equation (5) on substituting values for b with $T = 20{,}000°$ and for $\lambda_2 = 6678$, $\lambda_1 = 4922$, it is found that $W_2 = 2.00\ W_1$ for the singlets, and for the triplets $W_2 = 1.76 W_1$. In other words, a leakage of energy corresponding to an equivalent width of 0.1 angstroms at λ4922 results in an emission of energy of 0.2 equivalent angstroms at λ6678, thus effectively weakening this line. A leakage of 0.1 equivalent angstroms at λ4471 results in an emission of 0.176 equivalent angstroms at λ5876.

The diagrams of figure 3 show the results obtained when it is assumed that W_1 equals 30 per cent. of the $2p - 4d$ line, and W_2 is calculated by the above formula. W_1 is subtracted from the measured equivalent width for the $2p - 4d$ line, and W_2 is added to the measured equivalent width of the $2p - 3d$ line. The other

[10] *Astroph. Jour.*, vol. 85, p. 481, 1936.

corrections suggested to allow for the blends at λ4144 and λ4024 have been evaluated and applied.

When these curves are compared with those obtained for the giant stars (ρLeonis, 55 Cygni, 67 Ophiuchi) it is seen that the first member of both the singlet and triplet series in the dwarf stars has now about the same intensity as in the giants. Such a situation is to be expected since Stark broadening has little effect upon the leading member of the series. The second member of each series has now about the same intensity as in a giant star of the same or neighbouring spectral class. Stark effect considerations lead us to expect that this line should be somewhat more intense in dwarf

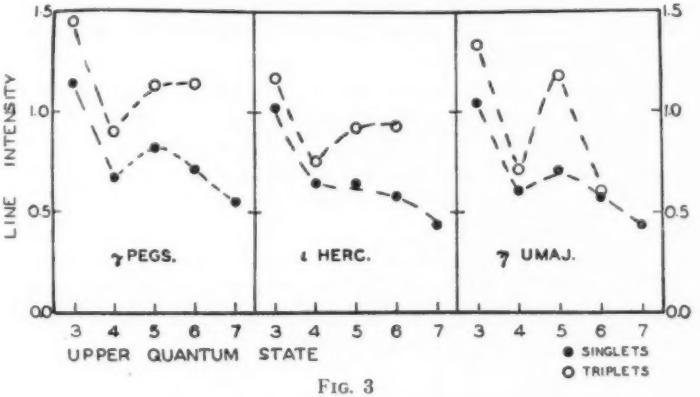

FIG. 3

stars than in giants. Stark broadening increases with increasing serial number, and a comparison of the strengths of higher members in the series in dwarf and giant stars shows that this is so. From these results it is seen that a Foster-Douglas leakage of 30 per cent. or a little less fully accounts for the weakening of the leading member and strengthening of the second member of the diffuse singlets and triplets. The great strength of λ4026 in the dwarf star ηUrsae Majoris still appears somewhat anomalous. However, since rotation greatly broadens the line profiles in this star, no clue to the origin of this rather large absorption can be obtained from the shape of the profile.

Actually, leakages as discussed here should also occur at the

$5d$-$5f$, and $6d$-$6f$ level pairs etc., since these are even closer than the $4d$-$4f$ level pair. The resulting absorption would be very difficult to detect since it would be very close to the d line, and and also there is much complex structure owing to the presence of Stark components. The most probable cycles are $5d \rightarrow 5f \rightarrow 3d \rightarrow 2p$, $6d \rightarrow 6f \rightarrow 3d \rightarrow 2p$ etc., causing emission in the fundamental series lines (infra-red) and in the $2p$-$3d$ lines. Thus all of the observed weakening of the $2p$-$3d$ lines will not be accounted for by absorption at $2p \rightarrow 4d \rightarrow 4f$ only. A leakage at the $5d$-$5f$ and $6d$-$6f$ level pairs of 0.1 equivalent angstroms results in an emission of over 0.2 equivalent angstroms at the $2p$-$3d$ lines. Thus small leakage absorptions at all of the d-f level pairs will together effectively weaken the $2p$-$3d$ lines, without the leakage being particularly dominant at any one level.

Since the anomalies in the helium line intensities in dwarf and intermediate stars are removed by the Foster-Douglas cycle, it seems likely that this hypothesis is correct. The suggestions of Struve and Goldberg are not satisfactory, since they do not explain the observed weakening in the intensities of the leading members of the helium diffuse series in dwarf stars.

In conclusion, the writers wish to thank all staff members of the Dominion Astrophysical Observatory for contributions to this work, and particular thanks are due to Dr. R. M. Petrie for his many helpful suggestions and comments.

University of B.C. and Dominion Astrophysical Observatory,
April, 1944.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Date of the Sun-spot Minimum

At the A.A.A.S. meeting in September last in Section D (Astronomy) the date of the minimum of solar activity was referred to, and it was stated that Dr. S. B. Nicholson of Mount Wilson Observatory had reported that the sun was free of spots during April 1944 and that the minimum was likely 1944.3.

At the request of the present writer, Mr. De Lisle Garneau of Montreal furnished a copy of his observations on the sun for the months of March, April and May, 1944. They are printed below. It will be noted that on 22 days between April 1 and May 27 no spots were observed. Mr. Garneau sent drawings for the days marked with an asterisk.

Observations of the Sun for March, April and May, 1944.
Station: Ville-Marie Observatory.
Long. 73° 37′ 18″ W., Lat. 45° 28′ 22″ N., Alt. 225 ft. above sea.
Observer, De Lisle Garneau. Inst., 6-inch refr.

Date	Hour E.T.		Remarks	Date	Hour E.T.		Remarks
1944	h	m		1944	h	m	
Mar. 4	15	25	No spots nor pores	Apr. 20	17	00	No spots nor pores
" 5	11	00	" " " "	" 22	12	30	" "
" 12	10	20	No spots; sky partly cloudy	" 26	17	10	" "
" 13	15	30	No spots nor pores	" 28	17	00	" "
" 14	10	20	" " " "	May 3	17	00	" "
" 15	11	00	" " " "	" 6	13	30	" "
" *18	12	30	3 spots	" 8	17	00	" "
" *19	10	30	3 "	" 10	17	15	" "
" *25	14	30	1 spot: 2 brt. faculae	" 14	10	25	" "
" *26	11	50	1 "	" 16	17	00	" "
Apr. 1	15	15	All spots and pores have disappeared	" 18	17	00	" "
" 3	17	10	No spots on sun	" 20	14	00	No spots nor pores
" 7	13	30	No spots nor pores	" 22	17	00	" " " "
" 10	16	55	" " " "	" 24	14	10	" " " "
" 14	17	00	" " " "	" 27	14	30	" " " "
" 15	12	30	" " " "	" *31	17	00	2 spots
" 18	17	00	" " " "				

C.A.C.

The Auroral Observation Group of the Montreal Centre

Mr. Charles M. Good, 2368 Hingston Ave., Montreal, Que., sends the following account of the activities of this Group:—

September 1944 saw the completion of the first year's activities of the Auroral Observation Group of the Montreal Centre, and it was thought that a summary of our experiences and methods, although of comparatively short duration, might be of some assistance and encouragement to those groups or individuals that may contemplate becoming "Aurora Bores."

This Centre, as far as can be ascertained, is the only one at present that is conducting organized observations of Aurora phenomena; and this, incidentally, is due in no small measure to the recent increase in membership, with some of the new members eager to do something of a practical nature.

To be of maximum value, regular observing is necessary; although Aurorae, on occasion, be few and far between, negative reports are of considerable usefulness in compiling statistical data. With this in mind, a group, twelve in number, was formed under the energetic leadership of Miss Isabel Williamson, our Recorder, to whom the success of this project is due.

To avoid concentration of observers in one locality, an effort was made to have the group composed of members whose locale was such that all horizons could be observed. The longitude and latitude of each was calculated and placed on record, using McGill University as a base. We are indebted to Mr. A. V. Madge for these figures.

Observers send their reports, both daily and monthly, to our Recorder, and for reference purposes and our own records, a combined monthly report is compiled. In addition, a copy is made of each daily observation form. The originals from each observer are then mailed to Dr. C. W. Gartlein at Cornell University Ithaca, New York. These forms are official and can be obtained from Dr. Gartlein, who will also supply instructions as to the proper classification of the various auroral types, etc.

When sunspots are visible on the sun and are of considerable dimensions, the occurrence of Aurorae is very likely. Advantage is taken of this relationship to give members advance notice of an impending display. Mr. DeLisle Garneau, a member of our group, is responsible for this feature. Dr. Garneau is a regular observer of the sun and during sunspot activity makes a series of drawings showing the progress of the spots.

Aurorae are more frequent than is commonly supposed. For example, at Ithaca, N.Y., 70 displays, to use a particular period, were observed between January 1938 and April 1939, an average of about five per month.

Of course, Aurorae may be present, but, due to sky conditions, such as fog, clouds and smoke—especially over cities—may not be visible. There are also times when there is some difficulty in deciding whether sky luminosity is an Aurora or an illuminated cloud. However, these problems are not without a means of solution in both circumstances.

In the case of an overcast sky, it is possible, by means of a pocket spectroscope, to detect the existence of Aurorae, even though the sky is completely

blanketed. To facilitate identification of phenomena, rendered difficult through the glare of city lights and smoke, special filters are also available.

There is no doubt as to the importance of these observations both in their contribution to related fields of astronomy and more recently to the war effort. As to the latter, Dr. Gartlein has made a special appeal for more observers, especially in southern Canada and the northern United States. The Arctic Institute of North America, recently formed in Montreal, has included observations of Aurorae and other electrical phenomena in their programme.

C.A.C.

Ideal Climate

The ideal climate would seem to be one in which the mean temperature of the hottest month of the year does not exceed 70° F., or at most 73° F., while the mean temperature of the coldest month does not fall below 40° F., or at lowest below 32° F. New Zealand offers what is in many ways the most attractive approach to this ideal, as over most of the country the mean temperature of the hottest month lies between 62° and 70° F., while that of the coldest month lies between 45° and 32° F. The healthy nature of the climate is borne out by the fact that, during the ten years 1926-35, New Zealand had a death-rate and an infantile mortality-rate of 8.4 and 40 respectively, both the lowest recorded values for any country in the world. The corresponding rates for the United Kingdom were 12.2 and 67 respectively.—David Brunt in "Climate, Weather and Man" in *Endeavour* for July 1944.

C.A.C.

MEETINGS OF THE SOCIETY

December 7, 1943.—The Society met at 8.00 p.m. in the McLennan Laboratory, University of Toronto; Miss R. J. Northcott in the chair.

Six persons were elected to membership in the Society, viz:

Mr. H. E. Allanson, 21 McCaul Street, Toronto.
Mr. W. E. Turner, 136 Clifton Road, Toronto.
Mr. R. Dunbar, 240 Jarvis Street, Toronto.
Mr. William Park, 83 Chudleigh Avenue, Toronto.
Mr. John R. Goudie, 86 Gloucester Street, Toronto.
Miss Edith Patterson, 152 Woodycrest Avenue, Toronto.

One member of the Society requested that his membership be transferred from the roll of Victoria Centre to Toronto Centre, viz:

Sergt. R. C. Crighton, 34 Moore Avenue, Toronto.

Dr. F. Shirley Jones then spoke on "Counting the Stars." The total number of stars in the sky, she said, was unknown because no count had ever been made of all regions of the Milky Way. A census, fairly well completed in several parts of the Milky Way, was now in progress with the goal of counting all stars down to the 15th magnitude. Such a count would give an approximate idea of the total of stars out to 5000 light-years, or one-sixth of the distance from the sun to the centre of the galaxy. At present there was not even an accurate estimate of how many stars were within 1000 light-years of the sun.

Three methods are used to determine stellar distances: 1, the trigonometrical parallax for stars to about 650 light-years; 2, determination of distance from proper motions, and 3, spectroscopic parallax measurements from the shift in the spectrum. Because there is not a very great range in stellar proper motions —from zero to an average of 20 km./sec. up to 100 km./sec.—it may be assumed that most stars with large proper motions are nearby while those with smaller proper motions are more distant. For stars that cannot be dealt with by this method, present equipment is able to determine spectroscopic parallaxes up to 5,000 light-years.

There are 48 stars within 16 light-years of the sun—only ten of them being visible to the naked eye, the others ranging down to the 14th magnitude.

When the distance of a star (d) and the apparent magnitude (m) are known, the star's true brightness or absolute magnitude (M) may be computed from the relation:

$$M = m + 5 - 5 \log d.$$

Stars vary over a range of more than 25 magnitudes in absolute brightness.

"Star counts can tell us the character of our own particular part of the Milky Way—whether the sun and its neighbouring stars are in a cluster, an arm or an open part of the galaxy," Dr. Jones said. They also serve to explain more about the dark patches and to tell us how far away these are, she added.

Miss R. J. Northcott presented the fourth paper in the series on "Funda-

mentals of Astronomy," dealing with distances, magnitudes and motions of the stars. The first measure of parallax of a star—the apparent change in position of the nearer stars against the background of more distant stars, due to the earth's revolution—was made by Bessel in 1838. Since then this has been the basis of determining distances of the nearer stars. The parallax of more distant stars may be determined indirectly: Cepheid variable stars from the period of light variations; double stars from the elements of the orbit (dynamical parallax), and from the relative intensity of lines in the spectrum (spectroscopic parallax).

Apparent brightness of a star depends on its real brightness and its distance. The absolute magnitude of a star is the magnitude it would have at the standard distance of 10 parsecs (32.58 light-years).

In 1718 Halley found that certain stars had changed their positions from those recorded by Ptolemy in the second century. This motion across the line of sight is called proper motion, and is expressed in seconds of arc per year. Barnard's star, with the largest known proper motion—10.25" per year—will take 180 years to move the angular diameter of the moon.

Motion along the line of sight is called radial velocity, and is expressed in kilometres per second. Radial velocity may be determined by the spectroscope, using the Doppler principle—if the star is approaching the lines in the spectrum are shifted to the violet, if receding, to the red. When proper motion and radial velocity of a star are known, the velocity in space may be computed.

The regular meeting adjourned at 9.30 p.m., to be followed by the annual business meeting of Toronto Centre.

FREDERIC L. TROYER, *Recorder.*

Annual Business Meeting, December 7, 1943.—The Annual Business Meeting was held following the regular meeting. Miss Ruth J. Northcott presided. Present: T. D. Waring, T. H. Mason, F. L. Troyer, Dr. D. W. Best, Rev. C. H. Shortt, H. Duncalfe, C. A. Crook, G. T. Dale, Mrs. H. S. Hogg, Miss E. M. Budd and others.

The Secretary, Tracy D. Waring, presented his report in which was reviewed the meetings held during the year and the growth in membership. In addition to the regular lecture meetings, four outdoor summer meetings were planned but two were cancelled because of cloudy weather. The Society took part in a special meeting in Convocation Hall on April 26 in commemoration of the 400th anniversary of the death of Nicholas Copernicus. On May 24 the Centre held its own meeting in honour of Copernicus when Dr. Frank S. Hogg was the speaker. On October 19 the Centre joined with the Royal Meteorological Society (Canadian Branch), the Royal Canadian Institute and the University of Toronto in afternoon and evening meetings to commemorate the 300th anniversary of the invention of the barometer by Torricelli.

Membership increased from 191 to 208 during the year, 40 members being added to the roll and 23 dropped for various reasons.

Moved by F. L. Troyer, seconded by C. A. Crook, that the Secretary's

report be adopted and sent on to the General Secretary for presentation at the Annual General Meeting and publication in the JOURNAL. Carried.

T. H. Mason, the Treasurer, presented his report on the Centre's financial condition. Moved by Mr. Mason, seconded by Dr. Best, that the report be accepted subject to approval by the auditors, and be forwarded to the General Treasurer for presentation at the Annual General Meeting and for publication in the JOURNAL. Carried.

The Nominating Committee appointed at the regular meeting of November 23 (Dr. Best, Mr. E. J. A. Kennedy and Mr. J. R. Collins) reported through Dr. Best that it recommended re-election of all Officers and Members of Council of the Centre. Moved by Dr. Best, seconded by Mr. G. T. Dale, that the report be approved.

The members present then voted unanimously for election of the Officers and Council, as follows:

Hon. Chairman—Dr. C. A. Chant.
Chairman—Miss Ruth J. Northcott.
Vice-Chairman—Mr. H. W. Barker.
Secretary—Mr. Tracy D. Waring.
Treasurer—Mr. T. H. Mason.
Recorder—Mr. Frederic L. Troyer.
Curator—Mr. R. S. Duncan.

Council—Dr. D. S. Ainslie, A. R. Clute, K.C., H. Duncalfe, Miss E. M. Fuller, Dr. L. Gilchrist, Flight-Lieut. J. F. Heard, Ph.D., Dr. Frank S. Hogg, J. H. Horning, Flight-Lieut. Peter M. Millman, Ph.D., W. T. Patterson, Rev. C. H. Shortt and Dr. R. K. Young.

Past Chairmen—J. R. Collins, E. J. A. Kennedy, S. C. Brown and Dr. D. W. Best.

The meeting was adjourned at 9.45 p.m.

FREDERIC L. TROYER, *Recorder.*

The Royal Astronomical Society of Canada

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President—A. Vibert Douglas, M.B.E., Ph.D., Kingston
First Vice-President—A. E. Johns, Ph.D., Hamilton
Second Vice-President—H. Boyd Brydon, Victoria
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General Treasurer—J. H. Horning, M.A., 198 College St., Toronto
Recorder—H. W. Barker, Toronto *Librarian*—F/L. P. M. Millman, Ph.D.
Council—C. S. Beals, Ph.D., Victoria; S. C. Brown, Toronto; G. E. Campbell, M.A., Hamilton; J. W. Campbell, Ph.D., Edmonton; W. G. Colgrove, M.A., B.D., London; DeLisle Garneau, Montreal; Mrs. F. Shirley Jones, Ph.D., Toronto; Mgr. T. W. Morton, Winnipeg; Paul H. Nadeau, Quebec; Andrew Thomson, Ph.D., Toronto; M. M. Thomson, Ottawa; G. M. Volkoff, Ph.D., Vancouver; and Past Presidents—J. A. Pearce, Ph.D. and F. S. Hogg, Ph.D., also the presiding officer of each Centre.

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Honorary President—F. W. Matley, Esq. *President*—T. L. Tanton, Ph.D.
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